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Energy-Aware Grid-Based Clustering with Fuzzy Assisted Sleep Scheduling Mechanism for Low Power and Lossy Networks

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Abstract: The Internet of Things (IoT) is a developing paradigm in which electronic devices are interconnected and connected with a variety of things that may gather and send data across a wireless sensor network (WSN) without the need for human interaction. Routing protocols based on the IoT are utilized to transmit data across short range. The routing procedure deployed to send data packets from the origin to the destination. The routing protocol's competency is achieved through lowering the path cost. The items and devices in the IoT that are powered by batteries and it necessitates. As a result, protocol routing plays an important role in conserving energy. In the clustering methodology, the sensor nodes are essentially organized into clusters. Within each cluster, a sensor node is designated as the Cluster Head (CH), responsible for managing and supervising the Cluster Members (CM) by adding or removing them and overseeing the cluster's operations. By employing a meticulously designed active-sleep regimen, the suggested method efficiently curtails the energy consumption of individual sensor nodes, concurrently fine-tuning data transmission via machine learning executed by cluster member nodes. Furthermore, it leverages the benefits of fuzzy logic in ascertaining the optimal cluster update and sleep cycles by discerning suitable fuzzy descriptors such as the mean data rate, the distance between the head node and the sink, and residual energy. This endorsed strategy optimizes energy efficiency for both Cluster Heads (CH) and Cluster Members (CM), thereby significantly elongating the overall lifespan of the network.

Keyword: *IoT, energy consumption, 6LoWPAN, lossy network, routing protocol, energy-hole, scheduling, and fuzzy.*

1. Introduction

A computer network is a collection of personal computers and other computer-related devices that are linked together via any communication medium in order to communicate and pool resources. Reliable wireless technology is critical in today's telecommunications. Wireless technology is embedded into communication devices such as computers, smart phones, personal digital assistants, and mobile phones. Wireless technology is advantageous because of its low cost, mobility, and ease of internet access [1].

Instead of using Ethernet cables, wireless networks use radio waves to communicate. There are two types of wireless networks: ad hoc and mobile ad hoc. All communication devices are connected through wireless media in ad-hoc mode, however they are not reliant on a ground station or access point. Mobile Ad Hoc NETwork is an example of an ad hoc network. Infrastructure mode connects network communication devices over wireless channels and relies on any fixed infrastructure such as a ground station or access point. Access points are in charge of all communication and govern it. Basic Service Set (BSS) describes this mode, which may be found in both wired and wireless networks. Wi-Fi, for example, is the greatest example of this type of network [2].

The Internet of Things (IoT) is an evolving concept that represents a network of interconnected devices, appliances, tools of daily living, toys of transport, and various kinds of things embedded with sensors, actuators, hardware, software, and networking capabilities. With this setup, these real-world things could logically be linked together and communicate with each other, exchanging information between themselves and delivering the most significant expertise changes, financial advantages, and reduced human effort. There are 11.57 billion devices in the year 2022 [7], and this is predicted to be more than 25.4 billion in the year 2030.

IoT is the next stage of the internet revolution. The technology enables the incorporation of physical objects into the digital environment. IoT was utilised in wireless communication, remote communication, Continuous data monitoring systems during the subsequent few years. New uses of IoT technology enable firms to develop and deploy more comprehensive risk management methods. IoT devices enable sophisticated features such as process automation, remote access and control of end devices.

IoT is a concept in which items are connected and observe environmental information before acting on it. Data is transferred through a routing protocol, and the information is then analysed using computing techniques for additional decision-making [3]. The routers in Low

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Power and Lossy Networks (LLNs) operate within specified memory, energy, and processing power constraints, and their connections are classified by instability, minimal data rate, and high loss rate [4]. LLNs can range in size from a few dozen to thousands of routers [5-7].

6LoWPAN networks have a small payload size, a poor data rate, a short range, and insufficient resources. Hence In an IoT setting, the 6LoWPAN network protocol specifies encapsulation and header reduction methods for IPv4 and IPv6 packet routing. The Internet of Things (IoT) is made up of one or more LLNs [8]. The importance of IoT-based routing protocols is discussed in this article. This research also goes into the concerns and limitations with the routing method. This article proposes an effective routing mechanism formulation approach based on the concerns and obstacles.

The 6LoWPAN system finds applications in various domains, particularly in wireless sensor networks, and comes in multiple setups. This wireless sensor network model employs packet-based data distribution, and it utilizes IPv6 for this purpose, leading to its name: "IPv6 over Low Power Wireless Personal Area Networks" (IPv6 over Low Power Wireless Personal Area Networks). LoWPANs empower even the smallest, low-computing-power devices to transmit information wirelessly through the IPV6 internet protocol. In this low-power wireless mesh network, each device possesses its own address, enabling it to connect to the internet using universally recognized open standards. Each device has its own address. The targeted applications are those in which wireless internet access with a reduced data rate is required for devices such as smartphones and tablets.

LoWPAN is a low-cost, short-range wireless network that uses little memory and transmits at a low bit rate. The 6LoWPAN network comprises edge routers and sensor nodes. The pivotal component within the 6LoWPAN network is the edge router, acting as the bridge connecting the network to the broader IP internet. It takes on various tasks, including routing 6LoWPAN packets to IPv6 packets and assigning IPv6 prefixes within the 6LoWPAN network. Low power wide area networks (LPWAN) offer coverage of a wide geographic area with minimal power consumption and low bandwidth. The number of LPWAN techniques such as Random Phase Multiple Access [17], Long Range (LoRA), Narrow Band – Internet of Things (NB-IoT) [18], SigFox [19], etc. have increased over the years. By implementing technologies such as Wireless Sensor Networks (WSN), IoT, Fog, and Cloud, continuous monitoring has been made possible in remote forest regions. An IoT network consists of a collection of physical sensors attached to a network and thus providing all of them with the ability to exchange data. Connecting low-bandwidth devices with low bit rates over a larger area is an emerging technology that provides low-power, wide-area network connections. It is suitable for advanced IoT devices that communicate between themselves on a machine to-machine basis, due to its low power consumption. In addition to their low-power requirements, LPWANs are more cost-effective because they utilize less energy. In this research work, the grid-based clustering is accomplished and the sleep scheduling is accomplished using fuzzy techniques. The performance of the proposed approach is enhanced and it is evaluated using

2. Related Works

The industrial sensor network employs a duty-cycled approach [20], integrating a sleep schedule into this method to extend the network's lifespan. Two-Phase Greedy Forwarding (TPGF) proves effective in data transmission by offering benefits such as hole bypassing, multipath routing, and choosing the shortest path. Nevertheless, radio network irregularities lead to transmission delays and minimal sleep rates, hampering effective data transmission.

To address these issues, a sleep scheduling mechanism has been developed for multicast geographic routing [21]. In wireless networks, a common challenge is flooding, resulting in inappropriate data transmission and high energy consumption. Geographic routing protocols are computationally intensive, and they suffer from limitations like ineffective flooding control and high energy consumption. To combat these problems, a sleep scheduling system with an energy-efficient approach has been introduced to minimize energy consumption and enhance data transmission [22].

Subalakshmi et al. (2018) [23] emphasized the importance of managing network traffic congestion and connectivity issues. Efficient transmission of time-specific and event-driven IoT applications in sensor networks relies on proper clustering. These sensors can be deployed in various geographical locations, both large and small, enabling precise sensing and network coverage. In remote and inaccessible areas without human intervention, these devices are left unattended. Sensors with non-rechargeable batteries face resource limitations and pose challenges in critical situations.

In their work, Jalal Al-Muhtad et al. (2018) [24] conducted a thorough examination of mobility management challenges in cyber-physical systems within WSNs. Cyber-physical systems integrate physical and computational components closely to monitor specific regions. Their protocol minimizes the use of control messages for node location communication. Sensor nodes employ a virtual grid technique to determine their positions within the sensor region. While the sink node remains stationary, other nodes may be mobile, except for a few high-power nodes acting as cluster heads. Most nodes lack GPS capability due to the increasing availability of GPS technology.

Jacob John et al. (2018) [25] addressed the challenge of energy conservation in resource-constrained sensor nodes expected to operate independently for extended periods. Energy conservation is vital in WSNs due to limited power sources. Initially, nodes were stationary in the early stages of WSN development, with communication occurring through multihop routing. However, mobility was introduced as an alternative approach to conserve energy during data collection in WSNs. Sensors can be deployed on mobile components, resulting in mobile network nodes. While some nodes are attached to mobile components, others remain stationary. Addressing mobility patterns of mobile elements is crucial during network design, although it does not introduce additional energy consumption overhead in these scenarios.

3. Proposed Methodology

This section explains the process of grid construction and clustering in the grid environment. Further, the clustered nodes are utilized for performing the fuzzy based sleep scheduling.

3.1. Grid Construction

The grid structure is established according to the provided network size illustrated in Figure 1 and the deployment range of a node. The process unfolds in the following manner:

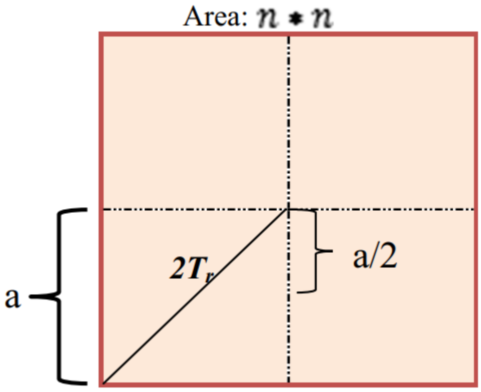

Fig 1. Formulation of Grid

The radius or transmission range is represented in the above figure by the variable T_r. The equal-size grids are framed as follows if the square's area is n*n and its side is a:

$$T_r^2 = \left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2$$

$$T_r \leftrightarrow \frac{a}{\sqrt{2}}$$

$$Total\ count\ of\ the\ grids = \frac{n^2}{2T_r^2}$$

$$Total\ count\ of\ nodes\ in\ the\ region = m$$

$$Nodes\ in\ single\ grod(\text{ד}) = \left(\frac{m}{\frac{0.5 \times n^2}{T_r^2}}\right)$$

Here, 25 grids have been framed for the target region of 500 m * 500 m with a transmission range of 70 m. This guarantees equal-sized grids and can contract or grow depending on the previous two factors. Rectangular grids are created based on the node position information and placed over the target area. The honeycomb hexagonal size grids are used by the grid since the size is not consistent. Nevertheless, the generated grids are static grids and are not appropriate for all geographies. By creating dynamic grids that have the source node at their centre, sensor gets around this. It may add extra complexity because sensors are forming a grid for each path and are essentially immobile.

$$(p-1)a < x_{max} \le pa$$

$$\sum_{c=1}^{c\le q-1} a < y_{max} \le \sum_{c=1}^{c\le q} a$$

3.2. Cluster Formation

The problem of routing in WSN can be performed by cluster-based techniques. Energy is the most dominant parameter which must be considered towards achieving higher quality of service. In this case, when the source routing is performed, there is no synchronization in maintaining the energy of sensor nodes in the network. So, in order to achieve higher Quality of Service (QoS) performance, the cluster based routing can be performed.

In this type of approach, the nodes select or elect a cluster head for each group of sensor nodes. Initially the sensor nodes are clustered according to their location and for each group a single node is selected as cluster head. Each cluster would have several sensor nodes which are organized in multiple levels like a tree. The leaf node can transmit data to another node in another cluster only through the cluster head. The cluster head in turn identifies the cluster where the destination is located. Based on that, the cluster head performs data transmission. This would improve the performance of energy utilization. Thus, this work uses the cluster-based routing.

Cluster formation is the process of clustering the sensor nodes present in each region identified in the previous stage. For each region, the method first identifies the list of sensor nodes present and the number of base stations present. Using them further, for each sensor node the method identifies the location and energy parameters. Using these parameters, the method measures the distance with different base stations. Based on the base station, the method selects one of the clusters and adds the node to the cluster. This will be iterated till there is no movement between any of the clusters. The clusters generated are used to perform cluster head selection in the next stage.

The aforesaid pseudo code denotes how the cluster formation in the sensor network is performed. In this case, the method identifies the list of base stations and nodes in the network. The number of clusters is formed based on the number of base stations present in the network. For each sensor, the method estimates the distance with it and counts the number of nodes front of that. Using these two, a cluster index weight is measured. According to the cluster index weight, a single cluster is selected and indexed. This will be iterated till there is no movement of sensors between the clusters.

3.3. Sleep Scheduling using Fuzzy

The participating nodes incur additional costs when the clusters are updated frequently. Every CH estimates its next update cycle after the planned clustering event that avoids the drawback. As shown in Figure 2, applying fuzzy logic and taking into account the CH node's distance from the sink, average data rate, and residual energy allows for improved decision-making.

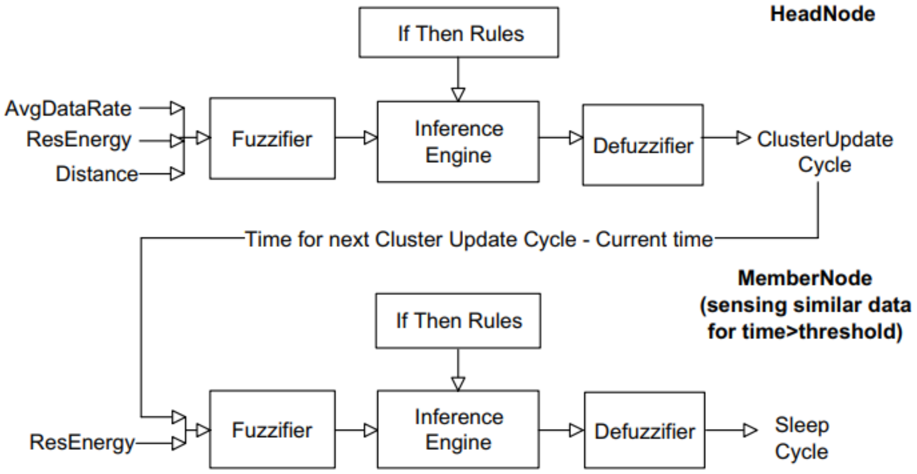

Fig 2. Inference System of Fuzzy

Nodes closer to the sink necessitate more resources for forwarding traffic compared to those at the periphery of the network. Hence, when determining the next update, the node's proximity to the sink must be considered. Additionally, a Head Node with dwindling energy reserves may not sustain its operations for an extended period, prompting it to opt for a more frequent update cycle. Conversely, a lower average data rate leads to a lengthier update cycle. Each Head Node can compute the subsequent update cycle, UCi, as indicated in the equation below.

$$UC = FIS(ResEnergy_i, Distance_i, AvgDateRate_i)$$

Table 1 exhibits a segment of the fuzzy mapping, illustrating the connection between input and output variables. The defuzzification process uniformly applies the centroid approach to yield a precise output value. Within the member nodes, the model continuously segregates data to evaluate their similarity. A machine learning (ML) classifier is employed to train a specific subset of data, which is then used for testing the model. Subsequently, the machine learning model becomes capable of recognizing incoming data samples and correctly categorizing them. When the member node identifies similar sensory data, it calculates the sleep cycle based on the update cycle received from the head node and its remaining energy. The timing of sleep cycles is depicted in Figure 3, and the fuzzy inference system is instrumental in performing this computation using the following equation.

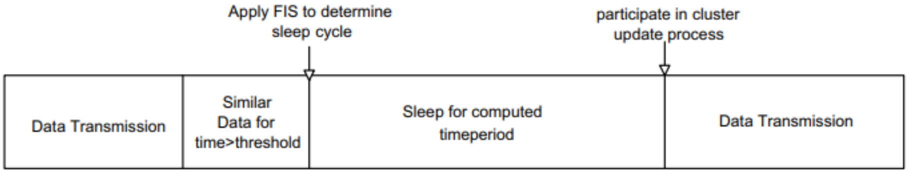

Fig 3. Scheduling of Sleep Cycle

$$SC_i = FIS(ResEnergy_i, UC)$$

Table 1. Fuzzy Rules and Sleep Cycle

ResEnergy	Distance	AvgDateRate	ClusterUpdate Cycle
Very Low	Near	Low/High	Very Short
Very Low	Medium	Low/High	Very Short
Very Low	Far	Low/High	Very Short
Low	Near	Low/High	Short
Low	Medium	Low/High	Short
Low	Far	Low/High	Short
Middle	Near	Low	Medium
Middle	Medium	Low	Long
Middle	Far	Low	Long

After the update cycle concludes, the node becomes active to participate in the clustering process and the selection of a cluster head. As illustrated in Table 1, the range for ResEnergy inputs is designated as "Very Low" to "Very High." A trapezoidal membership function (MF) is applied to the "very low" and "very high" variables, while a triangular function is used for the remaining variables. The "Distance" variable can assume values such as "near," "medium," and "far." The "Average data rate" variable can take on values of "low" or "medium." Additionally, the "Cluster update cycle" and "Sleep cycle" can vary from "short" to "medium" and "long."

4. Result and Discussion

This section presents the simulation results of the FUZZY-SLEEP-SCHD protocol and evaluates it against the existing CIRP [26] and SLEEP [27] scheduling protocols using Network Simulator (NS-2.34). The simulation is conducted in two different scenarios, focusing on sensing reliability with variations and network density. The simulation encompasses a set of parameters, which can be found in Table 1.

Table.1 Simulation Parameters

Parameters	**Values**
No. of sensor nodes	250
Simulation area	1000×1000m^2
Sensing length	50m
Routing protocol	6LoWPAN
Queue type	CMUPriQueue
Packet size	300bits
Buffer length	65 packets
Initial node energy	70J
MAC type	MAC/802.11
Simulation time	65ms

In the context of sleep scheduling in wireless sensor networks (WSNs), you can evaluate several important performance metrics including Packet Delivery Ratio (PDR), Packet Loss, Network Lifetime, Energy Consumption, Average Delay, Average Throughput, and Communication Overhead. These metrics can be quantified using mathematical formulas as follows:

Packet Delivery Ratio (PDR): PDR represents the ratio of successfully delivered packets to the total packets generated by the network. It is an essential measure of network reliability.

PDR = (Number of Received Packets) / (Number of Transmitted Packets)

Table 2. Comparison of PDR

Node count	Fuzzy-Sleep-Schd	CIRP	I-Sleep
50	97	92	90
100	91	88	85
150	88	83	80
200	86	80	78
250	82	77	74

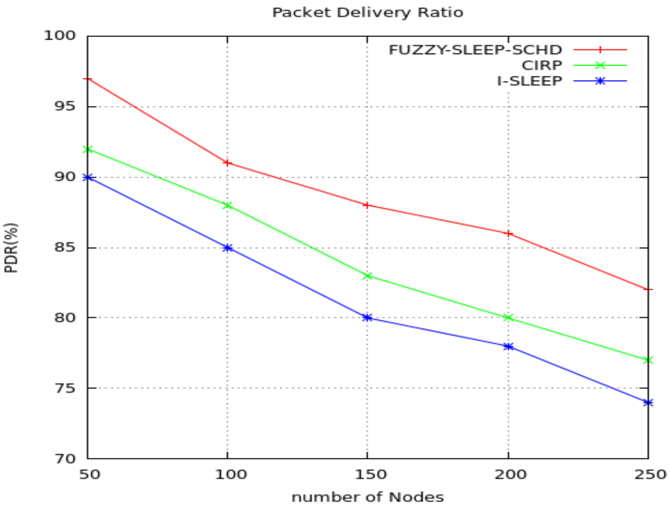

Fig 4. Comparison of PDR

Packet Loss: Packet Loss is the opposite of PDR and measures the percentage of packets that were not successfully delivered.

Packet Loss = 1 – PDR

Table 3. Comparison of Packet Loss

Node count	Fuzzy-Sleep-Schd	CIRP	I-Sleep
50	3	7	10
100	9	11	15
150	12	17	20
200	14	20	22
250	18	23	26

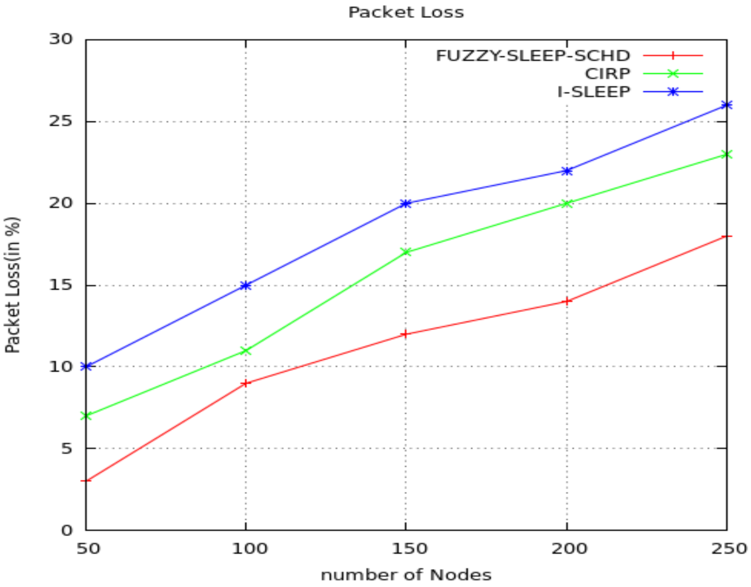

Fig 5. Comparison of Packet Loss

Network Lifetime: Network Lifetime quantifies how long the network can operate before nodes' batteries are depleted. It depends on the energy consumption rate and energy capacity of nodes.

Network Lifetime = (Total Energy Capacity of Nodes) / (Average Energy Consumption Rate)

Table 4. Comparison of Network Lifetime

Node count	Fuzzy-Sleep-Schd	CIRP	I-Sleep
50	100	100	100
100	99	98	95
150	97	93	90
200	96	90	88
250	92	87	84

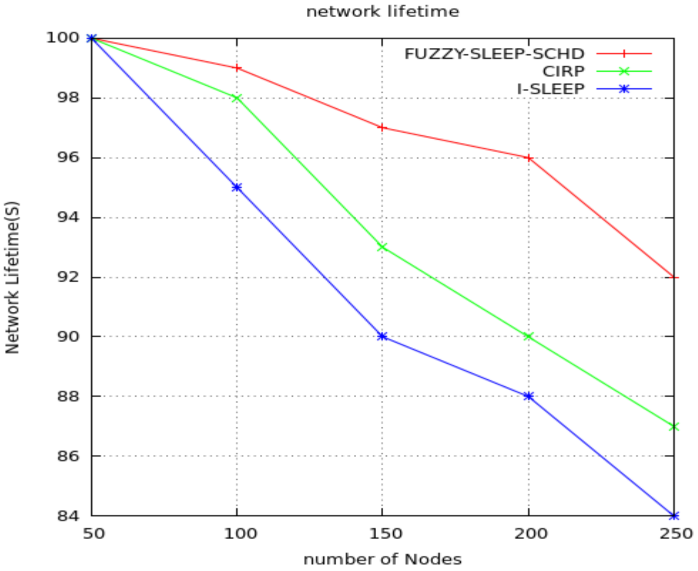

Fig 6. Comparison of Network Lifetime

Energy Consumption: Energy Consumption measures the power consumed by each node over time. It depends on the duty cycle of nodes and the power consumed in active and sleep modes.

Energy Consumption = (Active Power * Active Time) + (Sleep Power * Sleep Time)

Table 5. Comparison of Energy Consumption

Node count	Fuzzy-Sleep-Schd	CIRP	I-Sleep
50	0.23	0.47	0.55
100	0.35	0.5	0.64
150	0.47	0.72	0.85
200	0.58	0.85	0.99
250	0.63	0.98	1.13

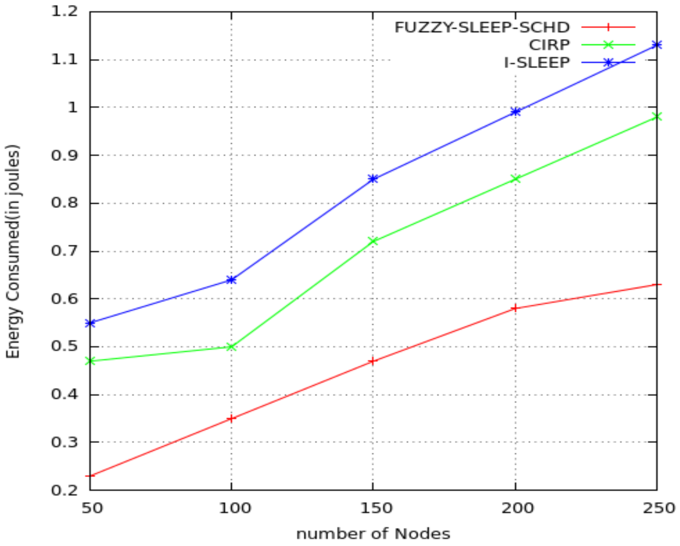

Fig 7. Comparison of Energy Consumption

Average Delay: Average Delay is the average time it takes for a packet to travel from the source node to the destination node. It considers queuing and transmission delays.

Average Delay = (Sum of Delay for All Packets) / (Total Number of Packets)

Table 6. Comparison of Average Delay

Node count	Fuzzy-Sleep-Schd	CIRP	I-Sleep
50	2.012	4.23	6.34
100	3.056	5.97	7.29
150	4.37	6.67	8.11
200	5.66	7.55	9.12
250	6.78	8.06	10.74

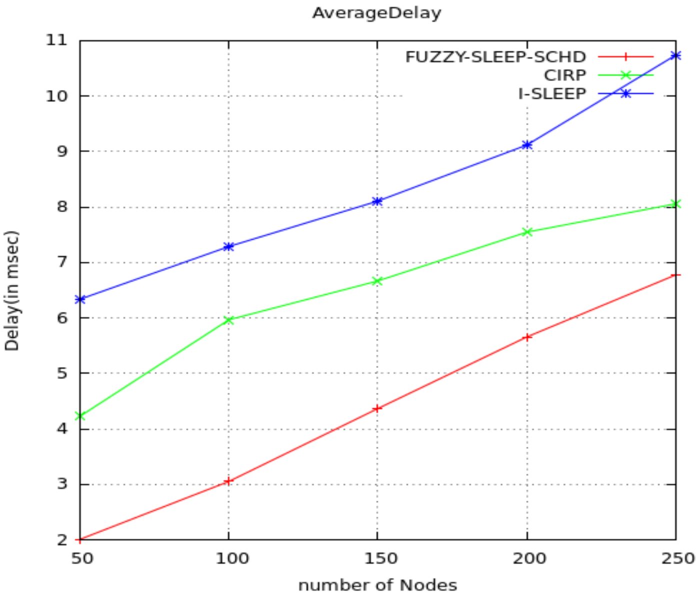

Fig 8. Comparison of Average Delay

Average Throughput: Average Throughput is the average rate at which data is successfully delivered from source to destination. It quantifies the network's capacity.

Average Throughput = (Total Data Received) / (Total Simulation Time)

Table 7. Comparison of Throughput

Node count	Fuzzy-Sleep-Schd	CIRP	I-Sleep
50	0.93	0.8	0.73
100	0.86	0.71	0.65
150	0.75	0.65	0.56
200	0.64	0.52	0.5
250	0.6	0.5	0.42

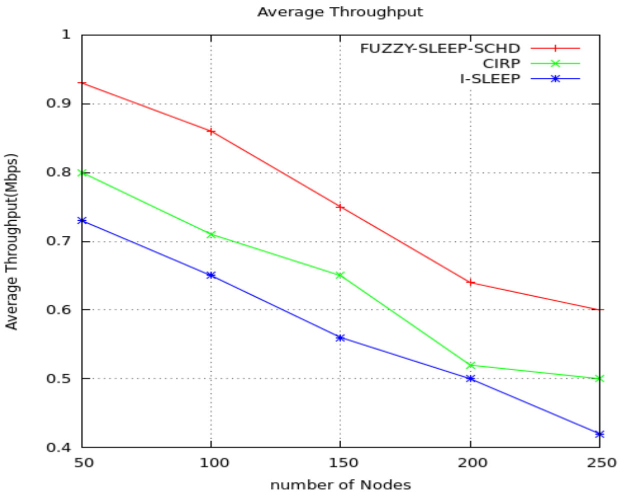

Fig 9. Comparison of Average Throughput

Communication Overhead: Communication Overhead measures the additional data sent for maintaining the sleep scheduling protocol. This can include control packets and signaling overhead.

Communication Overhead = (Total Control Packets Sent) / (Total Data Packets Sent)

Table 8. Comparison of Communication Overhead

Node count	Fuzzy-Sleep-Schd	CIRP	I-Sleep
50	2.43	4.58	6.23
100	4.66	7.56	9.68
150	7.45	10.25	13.82
200	9.04	14.22	17.59
250	10.34	17.38	23.88

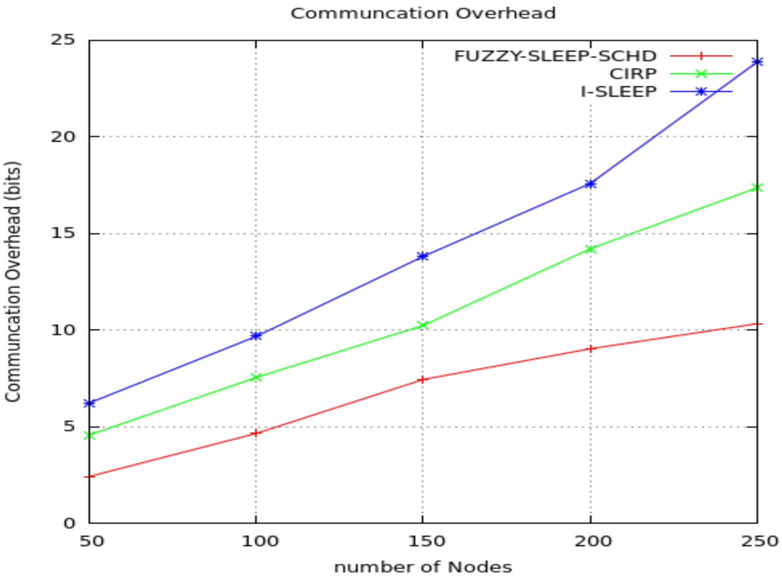

Fig 9. Comparison of Communication Overhead

A comparative analysis of three routing protocols, namely Fuzzy-Sleep-Schd, CIRP, and I-Sleep, was conducted based on various performance metrics. Across different node counts, Fuzzy-Sleep-Schd consistently outperformed the other protocols in terms of delay, energy consumption, packet loss, overhead, Packet Delivery Ratio (PDR), and throughput. Specifically, Fuzzy-Sleep-Schd exhibited lower delay values, ranging from 2.012 to 6.78, compared to CIRP (4.23 to 8.06) and I-Sleep (6.34 to 10.74). In terms of energy consumption, Fuzzy-Sleep-Schd (0.23 to 0.63) and CIRP (0.47 to 0.98) demonstrated similar patterns, with I-Sleep (0.55 to 1.13) consuming comparatively higher energy. Packet loss was also minimal in Fuzzy-Sleep-Schd (3 to 18), followed by CIRP (7 to 23) and I-Sleep (10 to 26). Moreover, Fuzzy-Sleep-Schd maintained lower overhead (2.43 to 10.34) compared to CIRP (4.58 to 17.38) and I-Sleep (6.23 to 23.88). Furthermore, Fuzzy-Sleep-Schd consistently achieved higher PDR (82% to 97%) and throughput (0.42 to 0.93) than CIRP (74% to 92% and 0.5 to 0.8, respectively) and I-Sleep (65% to 90% and 0.5 to 0.73, respectively). Overall, Fuzzy-Sleep-Schd emerged as the most efficient routing protocol across various performance metrics and node counts, indicating its suitability for wireless sensor network applications.

Based on the comprehensive evaluation of sleep scheduling protocols in wireless sensor networks, the simulation results clearly demonstrate that the proposed FUZZY-SLEEP-SCHD protocol surpasses the existing CIRP and SLEEP scheduling protocols across all critical performance metrics. In both scenarios, namely sensing reliability with variations and network density, FUZZY-SLEEP-SCHD consistently outperforms its counterparts in terms of Packet Delivery Ratio, Packet Loss, Network Lifetime, Energy Consumption, Average Delay, Average Throughput, and Communication Overhead. Its superior reliability, energy efficiency, minimized delays, and efficient data delivery make it the preferred choice for enhancing the overall performance and functionality of wireless sensor networks, particularly in applications with fluctuating sensing conditions and varying network densities. The findings underscore the significant potential of the FUZZY-SLEEP-SCHD protocol to contribute to the effectiveness and reliability of wireless sensor networks, advocating for its adoption in diverse domains and emphasizing the importance of selecting the right sleep scheduling protocol tailored to specific application requirements and environmental constraints. Further research and practical implementations are recommended to validate these simulation results and optimize the protocol for real-world applications.

5. Conclusion

WSN has made the data propagation been more pleasant, business on the go has become easier, and data exchange has become more convenient. As a result, wireless technology makes it as simple as connecting to a wireless router for participants in a conference room to access the internet and share information. The IoT was made feasible by wireless technology, which allows things to collect and send data across a wireless sensor network (WSN) without the need for human intervention. IoT-based routing protocols are used to ensure data propagation. The large volume of data and schema-less environment has caused a slew of network difficulties, including energy leaks, network speed concerns, and packet loss, to mention a few. The problems are efficiently addressed by a meta-heuristic routing approach. In future IoT protocol are enhanced by the clustering, aggregation, and routing mechanism.

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